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THE EFFECT OF HIGH TEMPERATURE OF THE CYLINDER HEAD ON THE KNOCKING TENDENCY OF AN AIR-COOLED ENGINE CYLINDER

By J. C. Sanders and M. D. Peters

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

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THE EFFECT OF HIGH TEMPERATURE OF THE CYLINDER HEAD ON THE KNOCKING TENDENCY OF AN AIR-COOLED ENGINE CYLINDER

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SUMMARY

The results of tests were combined with published data to determine the extent to which the knocking tendency of an air-cooled engine cylinder is increased when the cylinder head is poorly cooled and when the cylinder temperature exceeds the maximum specified by the engine manufacturer. A single-cylinder engine equipped to provide separate control of the air passing over the cylinder head and the air passing over the cylinder barrel was tested with 100-octane fuel.

The tests showed that, when the cylinder-head temperature was increased from 400° F to 600° F, the knock-limited indicated mean effective pressure was reduced 3 percent at a fuel-air ratio of 0.097 and 39 percent at a fuel-air ratio of 0.065.

An analysis of the published data on the sensitivities of eight representative fuels to combustion-air temperature indicated that with one exception these fuels are less sensitive in respect to cylinder temperature when used in rich mixtures than when used in lean mixtures.

It was therefore concluded that, under conditions of take-off and high-power operation, the maximum temperature of the head of an air-cooled cylinder is not usually limited by a consideration of knock; operation at conditions of maximum economy may be impossible because of a reduction in the knock limit accompanying high cylinder-head temperatures.

INTRODUCTION

Previous research on knock has revealed that increases in cylinder temperatures increase the tendency of an engine to knock. The data in table 2 of reference 1 show that increasing the jacket temperature decreased the value of the compression ratio at which knock occurred. One of the problems in cylinder cooling has therefore been to prevent cylinder temperatures from becoming high enough to seriously reduce the maximum permissible indicated mean effective pressure of the engine.

In a résumé of work done in England on Rolls-Royce liquid-cooled aircraft engines, Wood presents a curve (fig. 21 of reference 2) that shows the effect of coolant-outlet temperature on the maximum brake mean effective pressure obtainable without knock. Data were taken at a fuel-air ratio giving best economy (probably 0.065 to 0.07) and at a fuel-air ratio giving maximum power (0.08 or higher). At the low fuel-air ratio, the knock-limited brake mean effective pressure was lowered 39 percent by increasing the coolant-outlet temperature from 70° C to 140° C (158° F to 284° F). At the higher fuel-air ratio the loss was 1 percent.

Reference 3 describes tests conducted to determine the effect of a wide variation in valve cooling conditions upon maximum permissible indicated mean effective pressure. The results of these tests are reproduced in figure 1. The most effective valve cooling condition was provided by circulating water through the hollow interiors of both intake and exhaust valves. Contrasting conditions were obtained by operating the hollow valves with no coolant. This extreme variation in valve cooling conditions resulted in a reduction in the maximum permissible indicated mean effective pressure of 6 percent at fuel-air ratios greater than 0.09. At a fuel-air ratio of 0.065 the reduction was 21 percent.

Tests to determine the effect of piston-head temperature on knock-limited power over a range of fuel-air ratios are described in reference 4. The tests were run on a supercharged CFR engine with three fuels and at two inlet-air temperatures. The piston-head temperature was varied by circulation of oil through passages in the crown of a liquid-cooled piston. Near the stoichiometric mixture an increase in the piston-head temperature of 80° F decreased the knock-limited indicated mean effective pressure 4.76 to 15.25 percent. At a fuel-air ratio of 0.10, the decrease was from 0 to 9.1 percent.

The data of references 2, 3, and 4 indicate that the knocking characteristics of a fuel are less sensitive to changes in cylinder temperatures when rich mixtures are used. Operation of an air-cooled cylinder should therefore be possible without a serious reduction of the knock limit at temperatures considerably higher than the limits now specified by engine manufacturers, provided that no other difficulties arise. No reliable data are available, however, to indicate how external temperatures of an air-cooled cylinder influence knock.

The tests reported herein show how an increase in the cylinder-head temperature of an air-cooled cylinder from 400° F to 600° F affects the maximum permissible indicated mean effective pressure when lean or rich mixtures are used. The temperature of the exhaust valve was maintained below 400° F by oil cooling to prevent a hot exhaust valve from masking the effects of the temperature of the other surfaces in the combustion chamber.

Data from reference 5 presenting the sensitivities in respect to knock of eight representative fuels of 100-octane number to combustion-air temperature were analyzed to show how operation with other fuels might have influenced the results of the tests herein described.

APPARATUS AND TESTS

Tests were conducted at the Langley Memorial Aeronautical Laboratory on a Wright C9GC cylinder that was mounted on an NACA universal test engine crankcase. The bore was $6\frac{1}{8}$ inches and the stroke was 7 inches; the compression ratio was 6.7. An oil-cooled exhaust valve of the type described in reference 3 was used. The fuel used was AN-VV-F-781, Amendment-5, containing 3.9 milliliters of tetraethyl lead per gallon and not more than 4 percent aromatics. The standard test setup as modified to provide independent control of the cooling-air flow over the cylinder barrel and head is shown in figure 2. Power output and fuel and air consumption were determined by standard test equipment. The temperature of the combustion air was kept constant by a thermostatically controlled electric heater and was measured by a thermometer.

A representative temperature of the cylinder head was measured by a thermocouple peened into the rear spark-plug bushing. Four thermocouples peened into the barrel at equal intervals at the middle fin indicated average barrel temperatures. In order to determine a temperature on the inside surface of the combustion chamber, a thermocouple junction was peened 1/10 inch from the inner surface of the cylinder barrel on the downstream side and at the limit of travel of the piston at top center.

Tests were run at fuel-air ratios of 0.097 and 0.065 and the temperature of the rear spark-plug bushing was varied from 388° F to 617° F by control of the cooling air. The occurrence of knock was recorded when two laboratory observers agreed that it was barely audible. For each determination of the audible knock limit, the manifold pressure was adjusted to about 2 inches of mercury absolute below the pressure at which knock became apparent. The valves controlling the flow of cooling air were regulated to produce an average temperature of 360° F at the center of the barrel downstream as well as the temperature of the rear spark-plug bushing required for the test. After these temperatures were allowed to stabilize for 15 minutes, the manifold pressure was increased until knock was distinctly audible. The engine was allowed to operate at this condition for 5 minutes and the cylinder temperatures, the fuel-air ratio, and the indicated mean effective pressure were recorded.

RESULTS AND DISCUSSION

The maximum permissible indicated mean effective pressure as limited by knock was found to be practically unaffected by cylinder-head temperature when a rich mixture was used but was considerably reduced by increasing the cylinder-head temperature when a lean mixture was used. (See fig. 3.) When the temperature at the rear spark-plug bushing was increased from 400° F to 600° F, the maximum permissible indicated mean effective pressure was reduced 3 percent at a fuel-air ratio of 0.097 and 39 percent at a fuel-air ratio of 0.065. These results were obtained with a combustion-air temperature of 150° F, which is somewhat lower than could be expected in a supercharged engine at high speed. A higher combustion-air temperature might have resulted in a more noticeable effect of temperature of the rear spark-plug bushing on the knock-limited indicated mean effective pressure, particularly at lean mixtures.

The thermocouple near the inside surface of the combustion chamber showed a temperature of 420° F when the rear spark-plug bushing was 400° F and 606° F when the rear spark-plug bushing was 600° F. The operating temperature of a sodium-cooled exhaust valve was estimated to change from 1160° F to 1270° F with a change in rear spark-plug bushing temperature from 400° F to 600° F. (These estimates are based on thermocouple measurements of exhaust-valve temperature reported in reference 6.) In reference 3 it was found that replacing a sodium-cooled valve (estimated operating temperature, 1250° F) with a water-cooled valve (estimated operating temperature, 300° F) increased the knock limit only 6 percent. Consequently, exchanging the oil-cooled exhaust valve used in this test for a sodium-cooled valve would have an insignificant effect on knock with rich mixtures using the fuel specified for the test but might accentuate the effect of cylinder temperature at lean mixture.

The results of the tests indicate that the knock limit is only slightly influenced by cylinder temperatures when rich mixtures are used but is appreciably influenced when lean mixtures are used. Such a conclusion, however, cannot be reached without qualifications because the knocking characteristics of some fuels are more greatly influenced by temperature changes than others.

Although small amounts of data are available to show the sensitivity of various fuels to cylinder temperatures, cylinder temperatures do influence knock through their effect on the temperature of the cylinder charge. It is possible, therefore, to obtain a comparison of fuels by examining the influence of combustion-air temperature on their knocking characteristics.

Figure 4 shows the effect of variation in combustion-air temperature on the knocking characteristics of eight fuels of 100-octane number. Data for this figure were obtained from reference 4. Table I gives the compositions of the fuels. For each fuel two knock-limit curves are shown; one was taken at a combustion-air temperature of 250° F and the other at 150° F. These curves show that the temperature sensitivity in respect to knock of the fuels is much greater with lean mixtures than with rich mixtures. The percentage decreases in maximum permissible indicated mean effective pressure resulting from raising the combustion-air temperature from 150° F to 250° F are compared in the following table at a lean mixture and at a rich mixture:

Fuel	Fuel-air ratio 0.065	Fuel-air ratio 0.11
1	12.0	2.9
2	17.0	8.3
3	15.0	3.0
4	20.0	8.4
5	8.1	10.0
6	17.0	5.2
7	19.0	2.1
S-1	16.0	1.9

All of the fuels except fuel 5 show knock limits more sensitive to temperature with lean mixtures than with rich mixtures and should therefore be influenced by cylinder cooling in the same manner as shown in figure 3. The data of fuel 5 are thought to be in error because the composition of the fuel indicates that its characteristics should be no different than those of the other fuels.

Aircraft engines almost invariably require a rich mixture to prevent overheating of pistons and valves at high-power operation. Under these conditions the influence of cylinder temperature on the knock characteristics of most fuels is probably so slight that it need not be considered in establishing a maximum permissible cylinder temperature. Under cruising conditions with lean mixtures, however, improved cylinder cooling would permit a higher brake mean effective pressure. Specified maximum cylinder-head temperatures for modern aircraft engines are generally based on observations of failures of cylinder materials from overheating rather than from considerations of knock.

CONCLUSIONS

An examination of the results of the tests herein described and of previously published data indicates the following conclusions:

1. Tests with a 100-octane fuel in an air-cooled cylinder at two fuel-air ratios showed that the cylinder-head temperature had practically no effect on knock when rich mixtures were used but showed considerable influence when lean mixtures were used. An increase in cylinder temperature from 400° F to 600° F resulted in a reduction in maximum permissible indicated mean effective pressure of 3 percent at a fuel-air ratio of 0.097 and 39 percent at 0.065.

2. The influence of cylinder-head temperature on knock depends upon the fuel used. Examination of previously published data on the sensitivities of eight representative fuels to combustion-air temperature indicates that with one exception the knocking characteristics of these fuels are less sensitive to cylinder temperature when used in rich mixtures than when used in lean mixtures.

3. When fuels insensitive to temperature are used in rich mixtures, the specification of maximum cylinder temperature for take-off or high-power operation need not be influenced by the effect of cylinder temperature on knock.

Aircraft Engine Research Laboratory,
National Advisory Committee for aeronautics,
Cleveland, Ohio.

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TABLE I - COMPOSITION OF EIGHT FUELS OF 100-OCTANE NUMBER

[Data from reference 5]

Fuel	Amount of tetraethyl lead per gallon (ml)	Composition
1	3.06	54 percent hydrocodimer blending agent in straight-run 74 base
2	6.17	33.7 percent alkylate blending agent in straight-run 74 base
3	3.06	52.6 percent alkylate blending agent in straight-run 74 base
4	2.98	46 percent alkylate blending agent in hydroformed base
5	2.97	42 percent alkylate blending agent in Houdry base
6	2.96	40 percent hydrocodimer blending agent in Houdry base
7	2.74	60 percent phosphoric acid isooctane blending agent in 40 percent light naphtha
S-1	0	Isooctane, commercial

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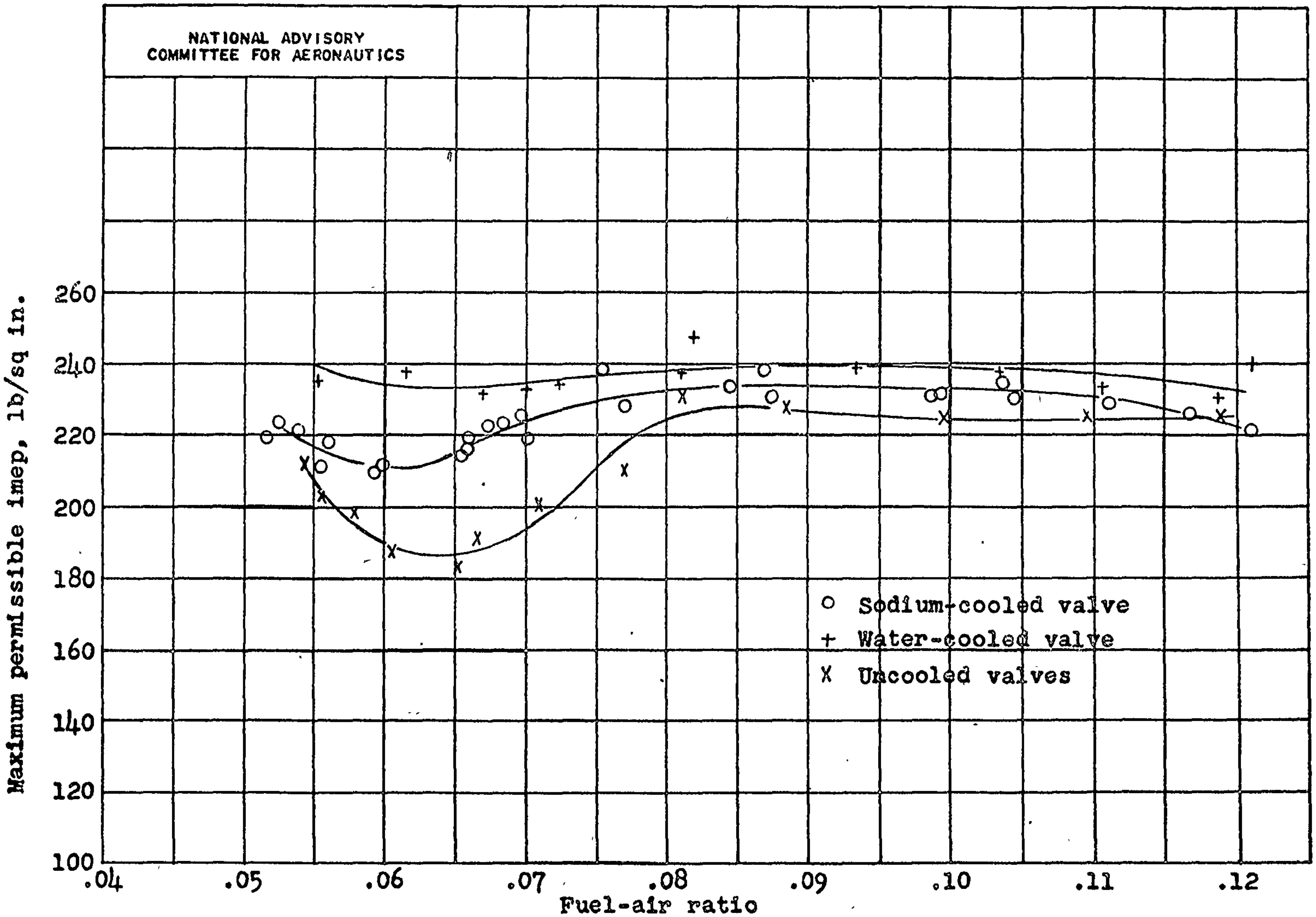

Figure 1.- Influence of extreme variation in the temperature of the exhaust valve upon knock in an air-cooled cylinder. (Fig. 7 of reference 3.)

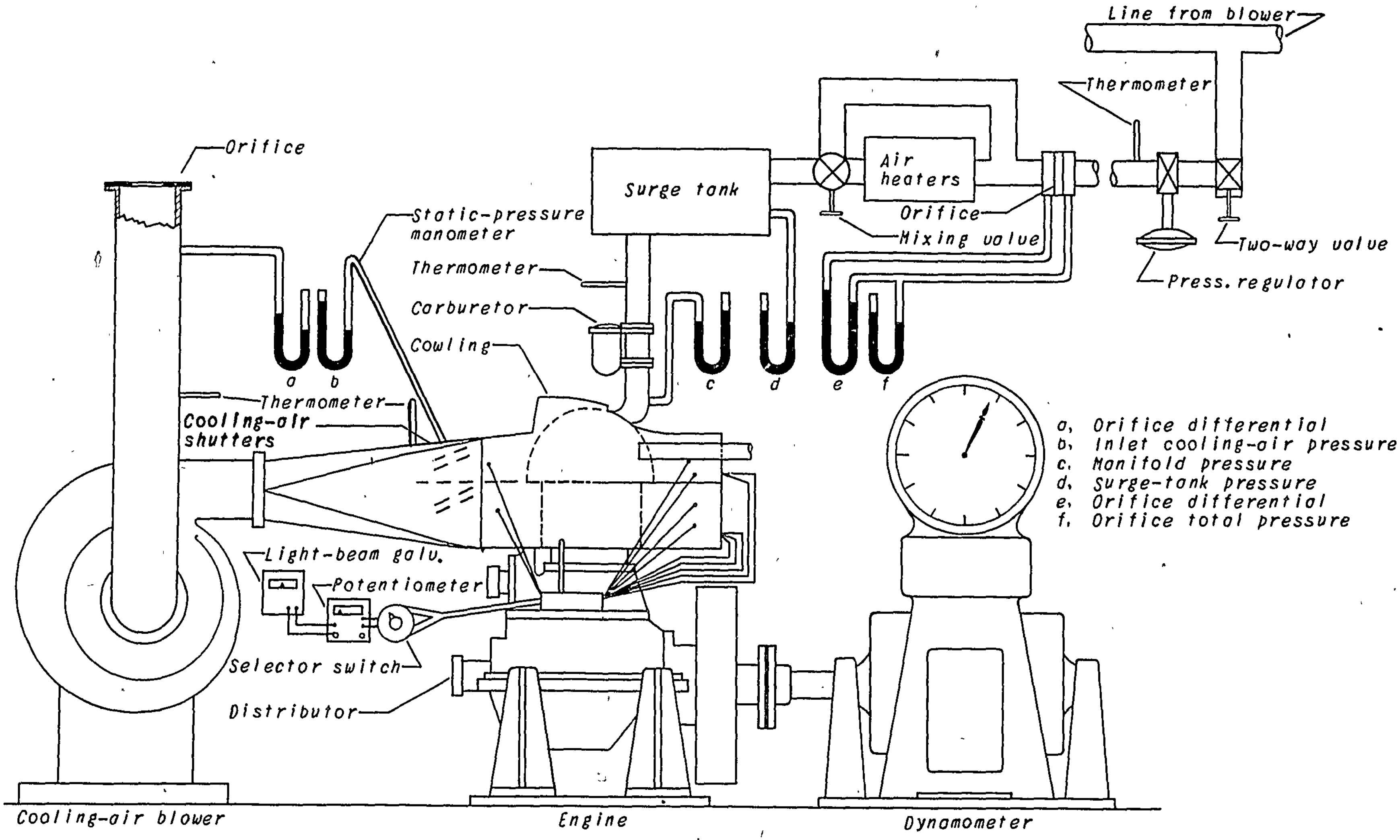

Figure 2. - Diagrammatic layout of test setup.

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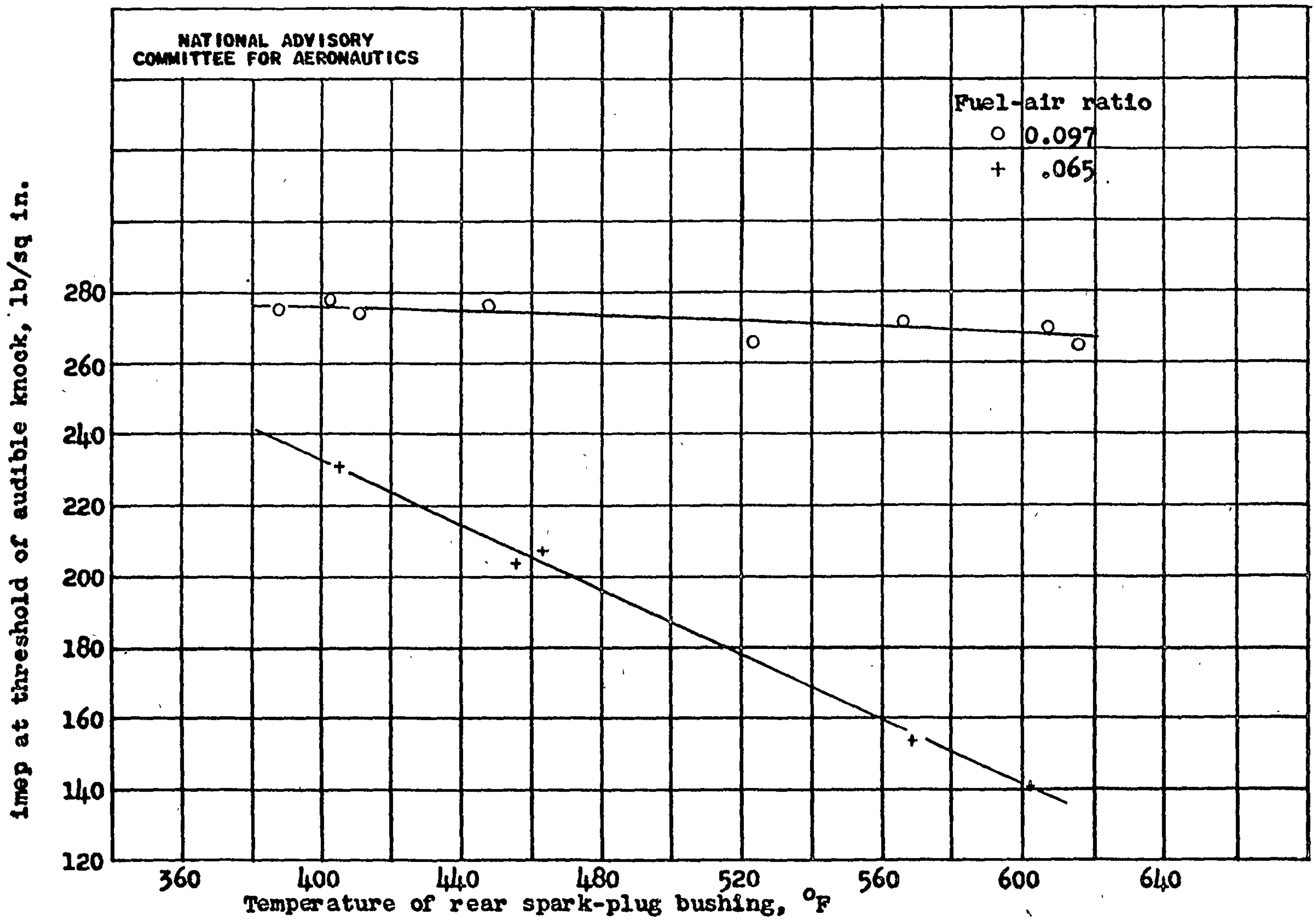

Figure 3.- Influence of cylinder-head temperature on the knocking characteristics of a fuel in an air-cooled cylinder. Wright C9GC cylinder; engine speed, 2200 rpm; combustion-air temperature, 150° F; fuel, 100-octane.

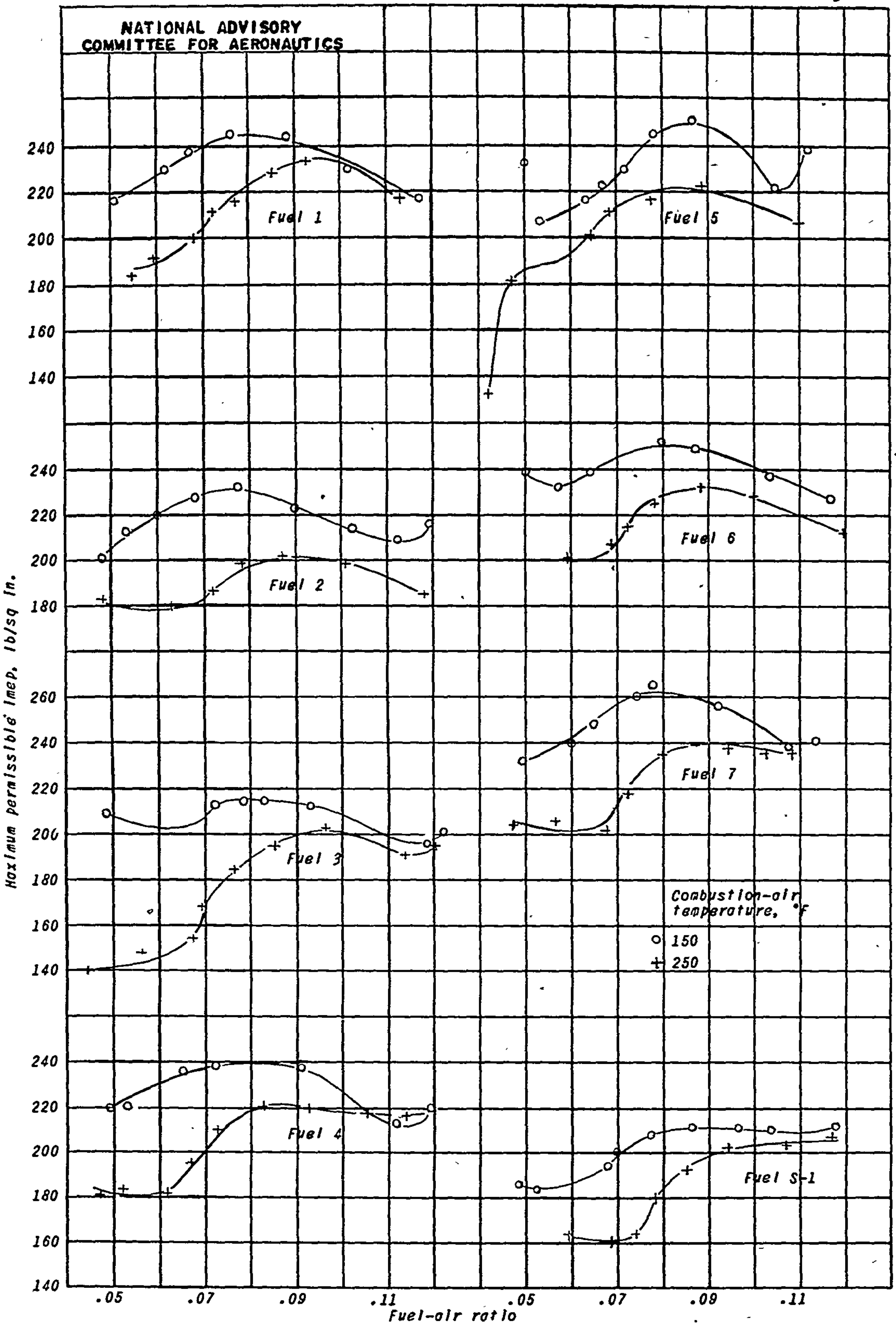

Figure 4. - Influence of combustion-air temperature on the knocking characteristics of eight fuels of 100-octane number. Lycoming O-1230 cylinder; engine speed, 2000 rpm; inlet coolant temperature, 250 °F; compression ratio, 7.0. (Data from reference 4.)